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SAMPLING IN TREE MEASUREMENT SALES ON NORTHERN REGION NATIONAL FORESTS

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Donald W. Lynch and Roy A. Chapman

March 1951

FOREWORD

Sample tree measurement has not been widely used in the Northern Region because of a lack of understanding of its principles and of the new techniques which it involves. Timber sales administrators need knowledge of the advantages and disadvantages of sample tree measurement, when and how it should be used, and the detailed methods for applying it. The present report explains all phases of this system of sale volume determination for the use of timber management specialists.

Those who care only for the detailed, step-by-step method of applying the system are referred to Part I of the Appendix, pages 30 to 42.

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INTRODUCTION

PURPOSE OF THE STUDY

Reliable short cuts or time-saving methods are urgently needed in routine phases of timber sale administration on the national forests. With a limited budget for conducting timber sale business, a forest officer often finds his time so completely occupied with the details of measuring the products that he must slight the more important forestry jobs such as marking timber, locating logging roads, and supervising sale procedures. Sample log scaling, tree measurement, and sample tree measurement can save time and money on the measuring job without a great sacrifice of accuracy.

Sampling is recognized as a reliable short cut in many fields of forest and range management. As sampling techniques are developed and understood, more and more confidence is placed in the results. Prior to 1941 there was a reluctance to use sampling in connection with the sale of forest products. It was believed that sampling just wasn't that good. However, in that year two publications presented some convincing results on the use of sample log scaling in Forest Service timber sales. (7, 8) 3/ Sampling methods were applied to log scaling

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3/ Figures in parentheses refer to literature cited.

in other regions of the United States following the appearance of the first publications, and in each instance sampling saved scaling time and gave acceptably accurate results. Employing the techniques learned in sample log scaling, the system was extended to sampling in tree measurement and it was found applicable to large sales in the Rocky Mountain and Southwestern Regions. (9)

The purpose of the present study was to apply sample tree measurement to the tree species and conditions found in the Northern Region (Montana, north Idaho, and northeast Washington). Emphasis was to be placed on the three kinds of trees most commonly tree measured in this region -- ponderosa pine, Douglas-fir, and western larch. Sampling intensities and techniques necessary for reliable estimates of volumes were to be studied for these species and for the range in timber sizes, defect conditions, and number of trees in sales that are commonly encountered. Stratified sampling was to be investigated to determine if sample sizes could be reduced without sacrificing accuracy.

SAMPLE LOG SCALING

Earlier studies have proved that a batch of 80,000 logs can be scaled with an accuracy of $2\frac{1}{2}$ percent by actually measuring only 4,000 logs. (7) If three percent were considered a satisfactory accuracy, 300,000 logs can be scaled by measuring only one out of every 100. As the number of logs to be scaled increased, the relative size of the sample decreases, but for any sale size above 5,000 logs, sampling saves time and gives acceptably accurate estimates. Furthermore, uniform sampling rates can be applied to logs of all sizes.

Another report (4) has described a process of sample scaling that could be applied to west coast logs where the range in log size was even greater than in the logs of the Rocky Mountains and southwest. The west coast log report included a table which showed the general range of sampling accuracies proposed for logs of varying defect conditions and stumpage value.

Sampling methods have been tested on northern Rocky Mountain logs, many of which are in double log lengths, and found applicable with some minor adjustments in sample size to provide for the greater range in volume of long logs. (12) In eastern Canada, investigations of sample scaling small logs and cordwood bolts ranging in length from 4 to 16 feet showed that sampling was practicable. (5) A study in the Lake States (6) revealed similar results.

Successful sample log scaling requires a relatively large number of logs in decks, or in a mill pond, or in a hot logging operation to make it cheaper than scaling every log. The method is simple. After the sampling intensity is decided, the scaler counts all logs

but measures only the logs indicated by the sampling rate. All personal bias in choosing the log to be measured must be eliminated by strict rules of selection. Accuracies of $2\frac{1}{2}$ percent or better can be obtained, which compares favorably with accuracies of complete log scaling based on check scales. The advantages lie solely in the reduced cost of scaling. If the time saved by a scaler in sample scaling cannot be profitably used elsewhere, he might just as well scale every log. Sample scaling is not being used much at the present time because large collections of logs are usually not available. Commonly, a scaler is kept busy by scaling only a few logs at several different sales, or he is required to stay on duty at one mill or landing where logs are not coming in at a rate that would make sampling advantageous. The present high stumpage values and the variety of species and prices in the same sale have also discouraged the use of sampling.

TREE MEASUREMENT

The high cost of log scaling and the large work load it creates on ranger districts where numerous sales are simultaneously in progress have led to the use of tree measurement in many Forest Service sales. With partial cutting and generally better silviculture being stressed in national forest timber management, marking every tree to be cut on timber sales is essential. The opportunity is therefore at hand for measuring the board-foot contents of the trees at the same time. The tree measurement process consists of measuring the d.b.h. and estimating the height. The volume for each tree is read from a volume table for the species concerned and recorded in a scale book. Numbering, as well as marking, each tree either with a blaze or a paint gun both above and below the point of cut is required. A certain percentage of the trees must be check scaled by measuring the logs after the trees have been felled and bucked in order to adjust the volumes determined by the tree measuring process. A ratio of scaled volume to tree measured volume for the same trees gives a correction factor to apply to the total tree measured volume. Errors in measurement, errors due to defect and breakage, and discrepancies in volume tables are found and adjusted by the check scale. Throughout this report, the term check scale will refer to the above-described process and not to the conventional process of re-scaling a number of logs to check the original scale.

Tree measurement has several advantages over log scaling. The timber can be marked and measured in one operation. Often better utilization can be obtained because the purchaser pays for every tree that is marked and must, therefore, remove all marked trees or suffer a loss. The necessity of a check scale requires the forest officer to visit the sale area frequently. Frequent visits to the sale area should result in better inspection and supervision. Tree measurement eliminates the need for cruising of sale areas. Units ready to be logged

can be marked and measured some time in advance of making the sale and thus a 100-percent cruise of the trees to be cut is available. Conventional cruises are frequently criticized because the cruiser's estimates and the subsequent marker's measurements do not agree on the volume to be cut. The sale volume often misses the cruise considerably, especially when a certain percentage of cut is attempted. Finally, tree measurement eliminates the many problems, both to the forest officer and the operator, associated with log scaling.

Tree measurement also has disadvantages. Operators as well as forest officers frequently question the accuracy of the scale. Inaccurate volume tables often cause substantial errors in sales having no provision for adjustments by a check scale. ^{4/} The use of volume tables will be discussed in detail later. Errors in volume determinations may arise when inexperienced personnel measure the heights and estimate defect.

The necessity of a check scale is a frequent and just complaint against tree measurement, yet proper check scaling is usually an essential part of the process, and the accuracy of tree-measured volumes often are poor because of insufficient or no check scaling. Pressure of other duties often makes it difficult for a forest officer to visit a sale area as regularly as he should to obtain an adequate check scale.

Unmarked trees cut in road clearing or by careless saw gangs, or because of logging damage, are not paid for unless they are detected and measured during sale inspections. Close sale supervision and careful location of roads prior to cutting are essential to prevent losses due to cutting of unmarked trees.

A final disadvantage of tree measurement is that current checks on amount cut for the purpose of collecting stumpage payments in advance are difficult to obtain. Loggers seldom cut the trees in the same order in which they were marked; therefore, the volume cut does not compare with any particular place in the scale book. Frequent inspections and a good knowledge of the sale area are essential to prevent cutting in excess of the payments. Some forest officers make a practice of marking only the volume of timber that has been paid for. Marking only what has been paid for is satisfactory on small sales that are moving slowly. However, on larger sales which require marking considerably in advance of logging, payment marking is not applicable. One forest officer required the logger to keep a record

^{4/} K. N. Boe (3) has outlined a method for adjusting regional volume tables for local use.

of the tree numbers from the cut trees as a basis for determining the amount cut. Asking a logger to report which trees have been cut takes control of this important accounting procedure away from the responsible forest officer.

Despite its several drawbacks, tree measurement is generally considered to be less expensive than log scaling under some conditions, and as personnel become better trained in its application, the system will increase in favor and in use.

SAMPLING IN TREE MEASURED SALES

Administrative costs on national forest timber sales can be further reduced by the use of sampling methods in tree measured sales. Lexen (9) pioneered in sample tree measuring just as in sample log scaling when, in 1947, he outlined a method to be used on large Forest Service sales in the Rocky Mountain and Southwestern Regions. The possibility had been suggested in 1945 by an investigator in the Pacific Northwest after applying sampling procedures to log scaling felled and bucked full-length trees in the woods. (10)

Sample tree measurement as considered here means marking and counting by species all trees to be cut on a sale but measuring only a certain percentage of them. Thus, the volume of a part is multiplied by the appropriate factor and becomes an estimate of the volume of the whole. The check scale, which is necessary in most cases, can be thought of as a sample within a sample where a few trees, accurately scaled after felling and bucking, provide a basis for correcting the volume derived from the large sample. In sample tree measurement, the volume must be kept separate by species because of the differing stumpage prices among species in the same sale. Different sampling rates for each species may be required because the total number of trees is usually markedly different by species. The process necessarily requires different forms and bookkeeping methods from the common scale book procedure, and a strict system of randomization in the selection of sample trees is essential. Unlike sample log scaling, a mechanical selection of sample trees is not appropriate because trees do not grow in such an order that the selection of every fifth tree, for example, could be free of human choice. The marker must not know in advance which tree is to be measured. Methods of accomplishing randomization for crew marking and individual marking will be discussed later.

Sample tree measurement has all the advantages of total tree measurement, plus being less expensive. Sale areas can be marked and measured considerably in advance of selling the timber. Log scaling is eliminated. More time can be devoted to sale area inspection and supervision, and the check scale sample can be gradually collected at the same time.

ACCURACY STANDARDS

Whenever the use of sampling is considered, the all-important question of accuracy standards must be defined. Sampling cannot yield completely accurate results, but the results can be evaluated and are assured with various probabilities to be within certain limits of accuracy. Furthermore, these limits can be narrowed to any desired amount by adjusting the sample size for a given set of conditions. In sample tree measurement on a given timber sale, some predetermined accuracy goal must be established in order to determine the sampling rate.

The accuracy objective should not be a fixed percentage for all conditions. The wide range in stumpage values as well as timber sale volumes requires that an appropriate accuracy standard be determined for each sale. A million board feet of western white pine sold for about \$25,000 at 1950 prices. A sampling error of only two percent in the volume determination on such a sale would mean a gain or loss of \$500. A million board feet of Douglas-fir and larch, on the other hand, might sell for as little as \$5,000, and, for the same actual monetary risk as in the white pine sale, a sampling error of 10 percent could be allowed. Yet it is not reasonable that an error as large as 10 percent should be used in selecting a sampling rate because with very little more expense, the error could be greatly reduced.

Sample sizes (or sampling costs) do not bear a straight line relationship to accuracy attained, as Figure 1 illustrates. That is, the cost of reducing a sampling error from 10 to 9 percent, for example, is much less than reducing it from 3 to 2 percent. For this reason the cost of achieving a given accuracy, rather than the percentage of accuracy, should be in proportion to the value of the sale. An appropriate sampling accuracy must be based upon both total sale value and sampling costs.

A practical method of determining sample size based on sale value and scaling costs has been described. (1, 2) The method offers a solution to finding the point of diminishing returns in sample scaling -- that is, the point where additional scaling in the sample would not reduce the possible error by as much as the extra scaling cost. By the diminishing returns principle, accuracy percentages will vary from sale to sale depending upon stumpage rates, scaling costs, and timber volume in the sale. From the seller's standpoint, the diminishing returns principle is a good approach to the accuracy problem. The volume is measured as accurately as is economically possible. However, the buyer usually has a different viewpoint. He is not burdened with the cost of achieving the accuracy and consequently wants the standard as high as possible to safeguard his purchase. A compromise between the seller's and the buyer's objectives may be necessary.

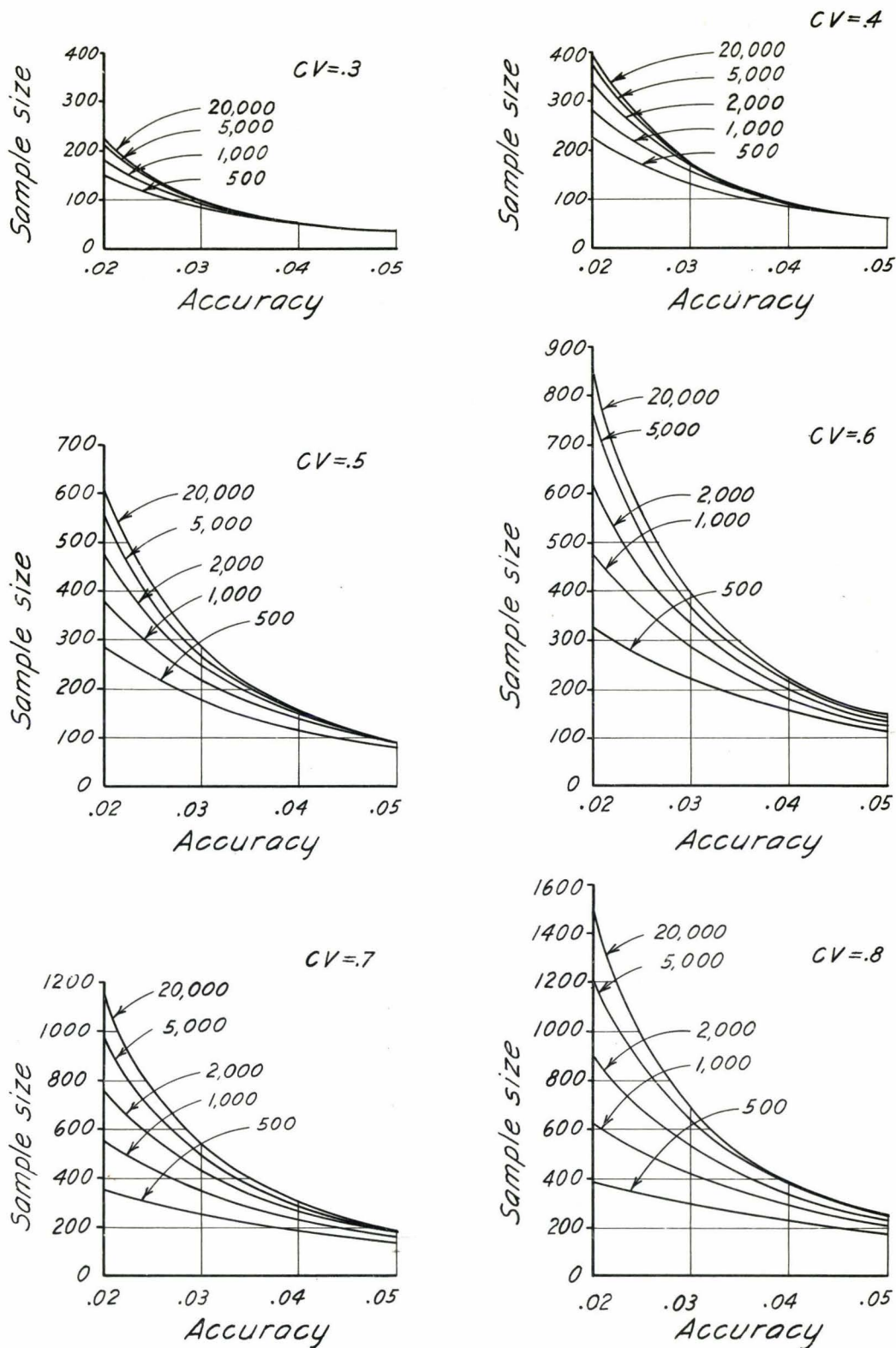


Figure 1.--Graphs showing the number of trees in the sample needed for accuracies of two percent to five percent, for sale sizes of 500 to 20,000 trees, and coefficients of variation of .3 to .8.

STUDY METHODS

COLLECTION OF DATA

Samples were collected from scale books of tree measured sales on the Bitterroot, Cabinet, Coeur d'Alene, Colville, Flathead, Kaniksu, Kootenai, and Lolo National Forests. Only a limited number of scale books were available because tree measurement is relatively new in the Northern Region. The samples covered as wide a range of conditions as possible. Twenty-four samples from ponderosa pine sales, 22 from Douglas-fir, 21 from western larch, 3 from western white pine, and 3 from Engelmann spruce were collected. In taking the samples from the scale books, rates of one in five to one in ten were used, depending upon the size of the sale. In every case, a sufficiently large sample was drawn to give a reliable estimate of the standard deviation of the tree volumes. Unlike collecting the sample in the woods, mechanical sampling from scale books can be considered unbiased.

A total of 41 lists of paired markers' and checkers' volumes covering different species and conditions were collected to study check scaling requirements. As data from check scales were even less available than tree measured scale books, the desired range in defect conditions could not be entirely covered.

FIRST SAMPLE ANALYSIS

The amount of variation in the volumes of trees on a timber sale is the most important factor in determining sample size for a given accuracy. The other main influencing factor is the total number of trees in the sale. The importance of volume variation can be appreciated by considering the hypothetical case where all trees in the sale have exactly the same volume. If the volume of only one tree is measured and all the trees are counted, a perfect estimate of the volume is obtained. However, tree volumes do vary, and so the sample of volumes must be increased as the variation increases in order to get a reliable estimate of the whole. Variation is commonly measured by the standard deviation. (Formula shown in Appendix II.)

Small trees have numerically smaller standard deviations than large trees. However, the relative variation, that is, the ratio of the standard deviation to the arithmetical mean commonly referred to as the coefficient of variation, was found to be rather uniform over the entire range of tree volumes. (See Appendix III.) The usual range of the coefficient of variation was found to be from 60 to 80 percent, with an occasional value as low as 40 percent or as high as 90 percent. The variation and mean volume for a sale are estimated from the sample. Multiplying the mean volume by the total number of trees in the sale gives an estimate of the total volume. The standard error of the

mean expressed as a percentage of the mean gives the sampling accuracy. Increasing the number of observations in the sample reduces the size of the standard error and enhances the accuracy of the sampling. Furthermore, by setting the accuracy at some predetermined amount, the size of the sample necessary to meet it can be determined. (See Appendix IV.) The process of estimating volume by a sample and evaluating its accuracy was followed in analyzing the data collected from scale books. Since each of these samples was drawn from a scale book in which the actual total volumes were known, the actual accuracy of sampling could be compared with the theoretical accuracy computed from the coefficient of variation and the sample size.

CHECK SCALE ANALYSIS

In analyzing check scale data, the coefficient of variation as well as the correlation, or amount of agreement, between the check scaled and tree measured volumes, are needed. (See Appendix V.) If the correlation coefficient is high (approaching one for perfect agreement) a very small amount of check scaling gives a reliable correction factor. However, if estimated and check scaled volumes of the same trees are poorly correlated, many measurements are necessary to determine the true correction factor. The number of trees required in the check scale depends mainly upon the amount of variation in the volumes and the correlation between estimated and scaled volumes of the same trees. Other factors affecting size of the check scale are the number of trees in the first sample and the relative cost of measuring a standing tree and check scaling a tree.

The amount of check scaling required to meet a given accuracy was determined for the various sales studied. (See Appendix IX.)

RESULTS OF SAMPLE TREE MEASUREMENT STUDY

RANDOMIZED SAMPLING

Coefficients of variation of tree volumes were found to be rather uniform throughout all the samples. Douglas-fir and larch volumes, however, had slightly lower coefficients of variation than ponderosa pine. This is to be expected, because the diameter range of ponderosa pine on the average timber sale is greater than that of the other species. Within a single species, about the same extremes in variation generally were found.

Ponderosa pine timber generally has coefficients of variation of around 70 to 80 percent, and Douglas-fir coefficients of around 50 to 60 percent. Occasional stands, however, with scattered, unusually large trees, might have larger variations. Methods will be discussed whereby some of this range in variation can be eliminated in choosing the sample.

No significant differences among forests in regard to variation in tree volumes were observed. Sampling techniques and rates can be uniform throughout the region. A measure of the variation for each particular sale that is to be sample tree measured should be obtained from cruise data, from comparison with other similar sales, or from a small preliminary sample. Ordinarily, in straight randomized sampling, if no reliable estimate of the variation can be obtained, then a sampling rate based on a high coefficient of variation (about 80 percent) should be chosen to be on the conservative side. (See table in Appendix I.)

The volumes attained in scale book sampling in this study agreed well with the actual scale book volumes. The accuracy percentages of the sampling based on the spread of one standard error above or below the sample mean, were as good or better than the actual accuracies of the volume comparisons in two-thirds of the cases - just as the theoretical probability would predict.

Sample tree measurement first gives an estimate of tree measured volume. That is, it is sure within known accuracy limits of being as good as a 100-percent tree measured job, which in itself may or may not be sufficiently accurate. In other words, a complete tree measured sale still needs correcting to bring it up to the standards of log scaling. However, this correction or "adjustment" is sometimes made arbitrarily from previous knowledge of defect conditions and tree measuring accuracies of similar timber. Especially on small sales, the practice of using a "judgement" correction factor is followed by many forest officers with satisfactory results. If the method is sufficiently accurate for full tree measured sales, it is equally good for sample tree measured sales. Figure 1 has been prepared to show the sample sizes needed for a range of variations, sale sizes, and accuracies. The appropriate sample sizes chosen with the aid of the graphs will give the indicated accuracies in terms of tree measured volume. Methods will later be discussed for determining sample sizes when check scaling is planned and when the chosen accuracy standards are based on scaled volume.

The sample sizes drawn from Figure 1 will give the indicated accuracies with a probability of 68 percent. That is, they are based on a spread of one standard error from the mean. If higher probabilities are desired, larger samples will be needed. A sample size drawn from Figure 1 to give an accuracy of at least two percent would, for example, give at least four percent accuracy with a 95 percent probability.

STRATIFIED RANDOM SAMPLING

Stratified sampling is the most efficient device for reducing the variation in tree volumes within a sample. Stratifying consists of dividing a population, in this instance trees, into strata of similar volume. A sample is then drawn independently from each stratum. The variation is composed only of the variation of the individuals within a stratum and all variation between strata is eliminated.

Large trees

The average timber sale contains a few scattered large trees, the total number of which is small compared to the entire number, yet whose volumes are a large part of the whole. By eliminating these trees from the sample, a large part of the variation can be eliminated. A sample drawn from the remaining trees can be smaller than before, yet provide the required accuracy. The volume of the large trees can be obtained by a 100-percent tally, which is entirely independent of the sample, and their volumes can merely be added on after calculating the volume of the remaining trees from the sample. Furthermore, the volume of the large trees will be free of sampling error, so the sampled trees can have a larger allowable error than has been established for the final result. The number of trees measured in the sample, plus the number of the large trees measured, will be less than the number necessary in a sample randomized over the entire stand.

To show the advantage of a complete measurement of large trees, a portion of the scale books were sampled in this manner. The results were compared with ordinary random sampling. Table 1 shows the number of trees required by the two methods for a sampling accuracy of 2.5 percent. The last column of the table lists the totals of the sample trees and the large trees. In each instance, the total is less than the first sample shown in column 2, which covered the entire range of tree sizes. A reduction in trees comes by cutting down the variation, as shown by the coefficients of variation in the table, and by eliminating all sampling error from large trees. An obvious question is: How large is a "large" tree? This cannot be answered definitely. The dividing point between "large" and "small" trees can be determined for each sale only by a trial method which is rather laborious. (See Appendix VI.) If too many large trees are measured, their number plus the sample trees is greater than a sample of the entire range of sizes.

Table 1.-- Sample sizes needed for accuracies of 2.5 percent, based on scale book samples; all values adjusted for a sale size of 2,000 trees for ease in making comparisons.

Unrestricted sampling		All large trees <u>1/</u> measured -- remainder sampled			
Coefficient of variation	Sample size	Coefficient of variation	Sample size	Large trees	Total of sample and large trees
<u>Percent</u>	<u>Number</u>	<u>Percent</u>	<u>Number</u>	<u>Number</u>	<u>Number</u>
<u>PONDEROSA PINE</u>					
49	320	36	100	162	262
64	500	53	289	93	382
65	513	50	214	175	389
67	525	52	244	91	335
72	584	58	280	142	422
74	588	60	320	104	424
75	625	68	510	15	525
77	643	70	500	25	525
79	666	62	303	81	384
81	688	69	340	69	409
<u>WESTERN LARCH</u>					
49	320	41	179	86	265
52	358	46	239	95	334
57	413	52	308	56	364
58	424	47	263	36	299
64	500	57	370	45	415
72	584	62	357	129	486
74	588	61	385	39	424
79	666	68	476	44	520
81	688	54	175	231	406
<u>DOUGLAS-FIR</u>					
58	424	45	217	42	259
58	424	47	217	90	307
59	435	52	263	27	290
60	447	48	278	33	311
67	525	51	286	43	329
68	535	58	357	72	429
70	555	63	400	73	473
88	770	62	263	157	420
93	833	78	455	92	547

1/ Large trees are about the upper 10 to 20 percent on the average small sale. See Appendix VI for methods of determining the number of large trees to tally completely.

Number of large trees

On sales of 1000 to 3000 trees, from 10 to 20 percent of the sample size usually can be devoted to a complete tally of large trees. In ponderosa pine a volume of about 2000 board feet, represented by a tree of around 34 to 36 inches d.b.h., was found to be a good dividing point in the scale books studied. In Douglas-fir and larch, a volume of 1000 board feet or 1500 board feet usually was used as the lower limit of large trees, depending on the number of such trees in the sale. As sale size increases, the relative size of the sample decreases (see Figure 1), but the number of large trees remains about a constant proportion of total trees. For sales larger than about four thousand trees, large trees can be sampled separately rather than tallied completely, the appropriate sampling rate being determined by the estimated variation and number of trees in the large tree stratum. The variation between strata, that is, between large and small trees, is thereby eliminated and increased efficiency gained.

Stratifying into three groups

A still further reduction in sample size can be made by dividing the tree volumes into three strata. (Appendix VII.) This was demonstrated on two sales where all large trees were tallied completely -- the most efficient dividing point having been established by trial -- and the remaining trees divided into "small" and "medium" strata. The size of the samples needed from each of these two strata was computed. These samples, together with the large trees, gave a much smaller total number than was needed in the original unstratified sample to meet the same sampling accuracy. Table 2 lists these results and shows how stratified sampling increases efficiency. As will be shown later, stratified sampling can be accomplished without undue burden to field men. Inasmuch as variation can be materially reduced by stratifying into three groups, Figure 1 shows sample sizes for coefficients of variation as low as 30 percent.

Stratifying by defect

Samples can also be stratified by defect classes if it is known that two or more easily distinguished defect conditions exist on the sale. If, however, defect is related directly to volume, as is often the case, then volume strata would cover both forms of variation.

Stratifying by area

Stratification by areas, that is, dividing a sale into blocks of known difference in regard to timber size or quality and sampling each block independently, is good sampling procedure. Ordinarily, however, a stratification by volume classes will eliminate more variation than area stratification because of the mixed size classes on most sales. An important advantage of area stratification is that sales can be divided into operating blocks and separate volume determinations made for each block. In cases of reappraisal or change of operators on a given sale, block stratification might prove to be of great value.

Table 2.-- Comparison of number of trees needed in sample to meet an accuracy of 2.5 percent without and with stratified sampling

Total trees in sale (number)	Number of trees needed in sample				
	Without stratified sampling	With stratified sampling			Total
		Large trees tallied completely	Sample of "medium" stratum	Sample of "small" stratum	
	<u>Number</u>	<u>Number</u>	<u>Number</u>	<u>Number</u>	<u>Number</u>
3850	1080	275	113	32	420
1192	435	104	30	41	175

In both tree measurement and sample tree measurement, it is difficult to determine exactly how much volume has been cut at any given time. If the sale area is divided into blocks, preferably according to timber size and quality for full value of stratification, then the determination of the amount cut at the end of a season, for example, is greatly facilitated. For ease in determining the amount cut periodically it might prove necessary on large sales to sample by separate blocks even if blocks were divided only according to a logging plan with no stratification of volume classes associated with them. Sampling by blocks would mean, of course, a larger sample proportionately in order to get the desired accuracy for a specific block, but with the use of volume stratification within blocks, the sample size might still be kept small enough for practical purposes.

Minimum limits for sampling

Stratifying makes sampling applicable on relatively small sales, but the exact size limit depends upon the highest sampling intensity that is considered practicable. Preliminary trials indicate that a sampling rate as high as one in three will prove to be a saving over complete tally. If this is true, then a sale of less than 2,000 trees can be sampled with an accuracy of 2.5 percent without stratification. With stratified sampling, the lower limit of sale size applicable could be less than 1,000 trees. Of course, as size of sale increases, the relative size of the sample decreases, as shown in Figure 1. On large sales, the sampling rate can be light. Figure 1 also shows the marked decrease in sample size obtained by lowering the standard of accuracy. Sales of low value species need not be measured with high accuracy to stay within a reasonable value accuracy. Sampling rates can be governed accordingly.

FIELD PROCEDURE FOR COLLECTING FIRST SAMPLE

Sampling must be practicable or it will not be adopted by timber sales administrators. Although based on rather complex theories, the actual application of sampling, fortunately, is simple, and the estimator does not require specialized statistical training. After a sampling rate has been determined for a given sale, the marking is carried out much as it is on a regular tree measured sale. Random selection of sample trees is greatly simplified by the use of a crew of three men; two marking and measuring and one recording is an efficient organization. Special forms for field use on which the randomization scheme can be set up in advance of field work are shown in the appendix. Provision must be made, of course, for a separate tally of each species and of each stratum if sampling is stratified. Appendix I gives detailed, step-by-step instructions for sample tree measurement training. Selecting sample trees with the aid of random numbers is described in Appendix X.

One man alone can sample tree measure, but with more than one species or size strata involved, the random selection of sample trees is difficult. A system such as the drawing of colored marbles must be used so that the man does not know in advance which tree will be measured. If the sampling rate is one in ten, then ten marbles, nine white and one black, for example, are needed. After a tree is selected for marking, a marble is drawn from one pocket and placed in the other. The color of the marble indicates whether the marker measures the tree, or merely counts it. The "two pocket" marble system, besides being cumbersome - especially in cold weather when the marker must wear heavy gloves - introduces a certain bias. For

example, if the black marble is the first one drawn, the marker knows that the next nine trees will not be sample trees. Or, conversely, if nine white marbles have been drawn, the marker knows that the next tree will have to be the sample tree.

The "one pocket" system of randomization in which the marble is replaced in the same pocket after each draw reduces the chance of personal bias but does not give assurance that the desired sampling rate will be maintained. Over a great many draws, if the marbles are carefully mixed each time, the desired ratio would be met, but on a small sale considerable error could be made in the sampling rate and hence in the tree count. Then, when the sample mean is multiplied by the total number of trees to obtain estimated total volume, a product of two errors is involved which greatly reduces the accuracy. Mechanical randomizers have been designed, such as the "Reinhardt Differential Selector," which follow the "one pocket" system, but the disadvantages already mentioned apply to this device as well.

Where more than one species is involved and the samples are stratified, one man has difficulty in keeping the various sampling rates straight. Crew marking is, therefore, recommended for sample tree measurement.

THE CHECK SCALE

Because of the many factors that contribute to errors in tree measurement, some of which can be eliminated with experience and some of which must be accepted, check scaling is usually necessary. It is the only way to insure that a tree measurement job is as good as log scaling. If the estimators have measured and recorded tree data accurately and the correlation between their volumes and the scaled volumes is high, the check scaling job is relatively easy. If their work was inaccurate, the check scale must be correspondingly larger to insure a proper correction factor.

Tree size as source of discrepancy

The correlation coefficient of markers' and checkers' volumes may be low for several reasons. Errors in measuring the trees by the estimator, especially in estimating height, often cause discrepancy between tree measured and scaled volumes. Even if no mistakes are made, the common practice of measuring d.b.h. to even inches (two-inch classes) and height to whole 16-foot logs introduces a large error. Consider, for example, a ponderosa pine tree recorded as 24 inches in diameter and five logs high, with a volume of 810 board feet. Its diameter might actually be anything from 23.0 inches to 24.9 inches, with a

corresponding volume as low as 735 board feet, or as high as 886 board feet, assuming the height is in fact 5 logs. The range in volume within the two-inch diameter class permits a plus or minus error of over nine percent. Now, if the tree actually has only $4\frac{1}{2}$ 16-foot logs, an additional error of almost 7 percent is introduced, yet the estimator has made no mistakes. On smaller trees the possible statistical error can be as much as 36 percent. Over a large number of measurements, such statistical discrepancies will compensate or "iron themselves out," but in check scaling the correlation of the volume of each scaled tree with the volume estimated for that tree influences the number of check scaled trees needed to meet a certain accuracy. Hence all practicable steps must be taken to improve the accuracy of the first estimate in order to reduce the discrepancy between the estimator's and checker's volumes.

It is recommended that d.b.h. of sample trees be measured and recorded by one-inch classes and heights be estimated by $1/2$ -logs. Also, more care and practice should be devoted to estimating heights. Inaccuracies of height estimates contribute as much as any other factor to poor correlation between markers' and checkers' volumes. However, with the sample tree measurement system it is reasonable to expect that accuracy of estimating heights will be improved because fewer trees will be measured and more care can be given them.

Defect

Defect contributes seriously to the discrepancy between estimated and scaled volume. One report states that defect was the greatest single factor that contributed to poor correlation between estimated and scaled volumes. (9) The present study did not bear this out, possibly because check scale data were not available for many of the sales, and hence a good cross section of defect conditions was not studied. It was not possible, from the data available, to set up a table in which a certain defect percentage called for a certain size check scale because too many other sources of error influenced the check scale.

It has been suggested that if defect were found to be a major source of the error between marker and checker, a random selection of logs at landings might be scaled and the defect percentage calculated from these, rather than to check scale a large number of full-length trees to arrive at the correction factor. Of course, a defect correction factor obtained from logs on landings would have to be applied to the estimator's gross volume, because his net volume has already deducted for part of the defect - a part not distinguishable from the whole. A poor representation of defect probably would be obtained if the logger made a practice of leaving defective material in the

woods. Furthermore, check scaling, disregarding defect, would still be needed in order to get a measure of breakage, volume table errors, and inaccuracies of measurement. Where defect is not a major source of error, scaling a group of randomly selected logs to arrive at a defect factor is not recommended because the need for check scaling in the woods would not be eliminated.

Culling for visible defect

Estimating visible or "detectable" defect in the standing tree and deducting it from the volume is highly recommended. This practice, of course, requires skill and experience and it is not expected that an accurate estimate of defect is possible. However, in many instances considerable improvement can be made in the volume determination by adjusting for defect. A cull tree, for example, that can be identified as such at the time of marking should not be included in either the sample or the tree count. It may or may not be marked for removal depending upon the conditions of the sale contract. A separate tally of cull trees might be desirable from a silvicultural standpoint.

Volume table errors

Volume table errors account for a large part of the discrepancy between estimator's and check scaler's volumes. To develop volume tables for universal application, even for a given forest or ranger district, without recourse to such measurements as form class is impossible. Knowing how the form and growth habits of a species such as ponderosa pine vary from one site to another, it is not surprising that complaints of volume table inaccuracies are common. Until local volume tables can be developed or training given in the use of form class volume tables, discrepancies are difficult to correct. (3) The experienced estimator can, however, make adjustments if he knows the basis upon which the volume tables in use were constructed in regard to top diameter and general form of timber.

Boe (3) illustrates common errors in application of volume tables by the following two examples:

"The first error arising from estimating to a different top diameter than the volume table provides for involves reducing a height estimate to correct for large limbs, crook, or other defect in the top log. The result will be to underestimate the actual volume. For example, a 24-inch ponderosa pine having five logs to an 11-inch top contains 810 board feet. Suppose that the top log is unmerchantable due to

large limbs. The top log contains approximately seven percent of the volume of the tree, or a reduction of 57 board feet if the log had been culled. Had the estimator dropped his height estimate a log to allow for the limby top, the volume of the tree would have been recorded as 700 board feet. Thus, in attempting to correct for 57 board feet of cull, the tree volume has been reduced by 110 board feet, an underestimate of about seven percent.

"The second error will result if heights are estimated to a smaller top diameter than specified in the volume table. Estimating usable top to a smaller size causes an over-estimate of tree volume as shown in the following example. A 20-inch ponderosa pine with four logs to a 10-inch top, contains 420 board feet. Suppose local utilization is to an eight-inch top, giving the tree an extra log. An eight-inch log will scale 30 board feet which added to the volume of the four-log tree gives a total actual volume of 450 board feet. If the tree had been estimated as a five-log tree to an eight-inch top, and the volume read from the table specifying a 10-inch top diameter, the gross volume would have been found to be 530 board feet, an over-estimate of 80 board feet or about 18 percent."

The use of local volume tables adjusted to fit the conditions for a particular type of timber is superior to correcting individually for each tree. The use of form class volume tables should also be encouraged. Such factors as unusual bark thickness on the lower bole and butt swell, caused by various defects, often are sources of errors in volume determinations. An experienced estimator can make adjustments of diameter if the tree is malformed and thus bring the estimated volume nearer the scaled volume.

Breakage

Breakage introduces discrepancies between estimators' and checkers' volumes which cannot be foretold. However, breakage usually creates only a minor part of the total error.

Check scaling standards and methods

The actual check scaling must, of course, be precise because the correction factor found by a relatively small check scale is applied to a large volume. Scaling in the woods, with logs and debris criss-crossed and log ends concealed, is a difficult job. Where a scale stick cannot be used on the ends of logs, calipers and a bark measuring

device are suggested. If calipers are not available, a diameter tape can often be placed around the end of a log to measure its diameter. Double bark thickness must be deducted. Unless the scaler has had considerable experience, large errors will be introduced by measuring across the tops of logs with a scale rule.

Further complications in getting a good check scale come from the difficulty of finding full-length trees to scale when the sale areas are inspected. Modern hot logging methods do not leave an accumulation of down timber in the woods. With sampling involved, this difficulty will be even more pronounced, as only sample trees can be check scaled. To facilitate finding the sample trees, at the time of marking and measuring distinguishing marks should be placed on these trees, such as ax blazes on three sides or extra-large paint streaks if the trees are being marked with spray guns. Furthermore, check scaling must be representative of the timber. Samples must be obtained by checking a few trees in scattered locations frequently, rather than by checking all in one small area at one time.

If the original sample is stratified, the check scale usually should be stratified in the same way, that is, a representative check scale obtained in each size stratum. If the correction factors found in the various strata do not differ materially from each other the check scaled data can be pooled for a common correction factor. The suitability of a common correction factor can be tested by plotting all the scaled volumes over their corresponding tree measured volumes. Two main requirements should be met: first, the relationship should be linear indicating that the correction is the same throughout the range of volume; and second, the straight line relationship should pass through the zero point on the graph indicating that there is no constant correction in addition to the percentage correction that must be applied. The line passing through the zero origin also insures that small trees do not have a plus correction and large trees a minus correction or vice versa.

SIZE OF SAMPLES

The relative cost of tree measuring and check scaling affects the size of the check scale sample required as well as the size of the first sample. The final volume estimate is determined by two samples; the first made in the standing trees and the second in the check scale. If one is highly accurate, the other can be less accurate. The best balance between the two must necessarily be based on the cost of getting them. Only estimates are available, because costs have not been studied systematically, but obviously, check scaling a single

tree is several times more costly than tree measuring it. The greater the spread in cost between initial measurement and check scale, the greater should be the accuracy of the first sample in order to reduce the amount of check scaling required to meet the final accuracy standards. The cost ratio can be determined roughly by estimating the time required to do the two jobs.

Tree measuring costs about 12 cents per tree. Check scaling under favorable conditions costs about 50 cents per tree, based on checking 40 trees per day at a cost of \$20. When sample trees have to be searched out, check scaling costs will be higher. Of course, a portion of the time spent on check scaling can be charged to sale inspection. Often a few trees can be check scaled incidentally to supervision or marking without much added expense. Probably 4 to 1 is a good average ratio to use for cost of check scaling to cost of tree measuring until a better one is developed through experience or special studies.

Figure 2 shows the first sample size required to give a desired accuracy when all factors are considered. This chart should be used for determining sample size whenever the correction factor is to be determined by check scaling instead of by a "knowledge correction factor." It gives sample sizes that will estimate log-scaled volume within the desired accuracy after the necessary check scaling is completed and the correction factor applied. The accuracies specified in Figure 2 are based on a 68 percent probability. (See Appendix VIII.)

Figure 3 shows the ratio of check scale sample size to first sample size for various correlation coefficients and cost ratios. The check scale sample size is found by multiplying the number of trees in the first sample, found in Figure 2, by the ratio shown in Figure 3. It is evident from an inspection of this alignment chart that a high correlation between marker's and checker's volumes reduces the check scaling job. For example, using a correlation coefficient of 0.7 and a cost ratio of four, it is found that over six-tenths of the trees originally measured must be check scaled. If a correlation coefficient of 0.9 could be used, only about one-fourth of the first sample need be check scaled. Thus, by improving efficiency of estimating, the amount of checking is materially reduced. A table in Appendix I gives a rough guide to the appropriate correlation coefficient.

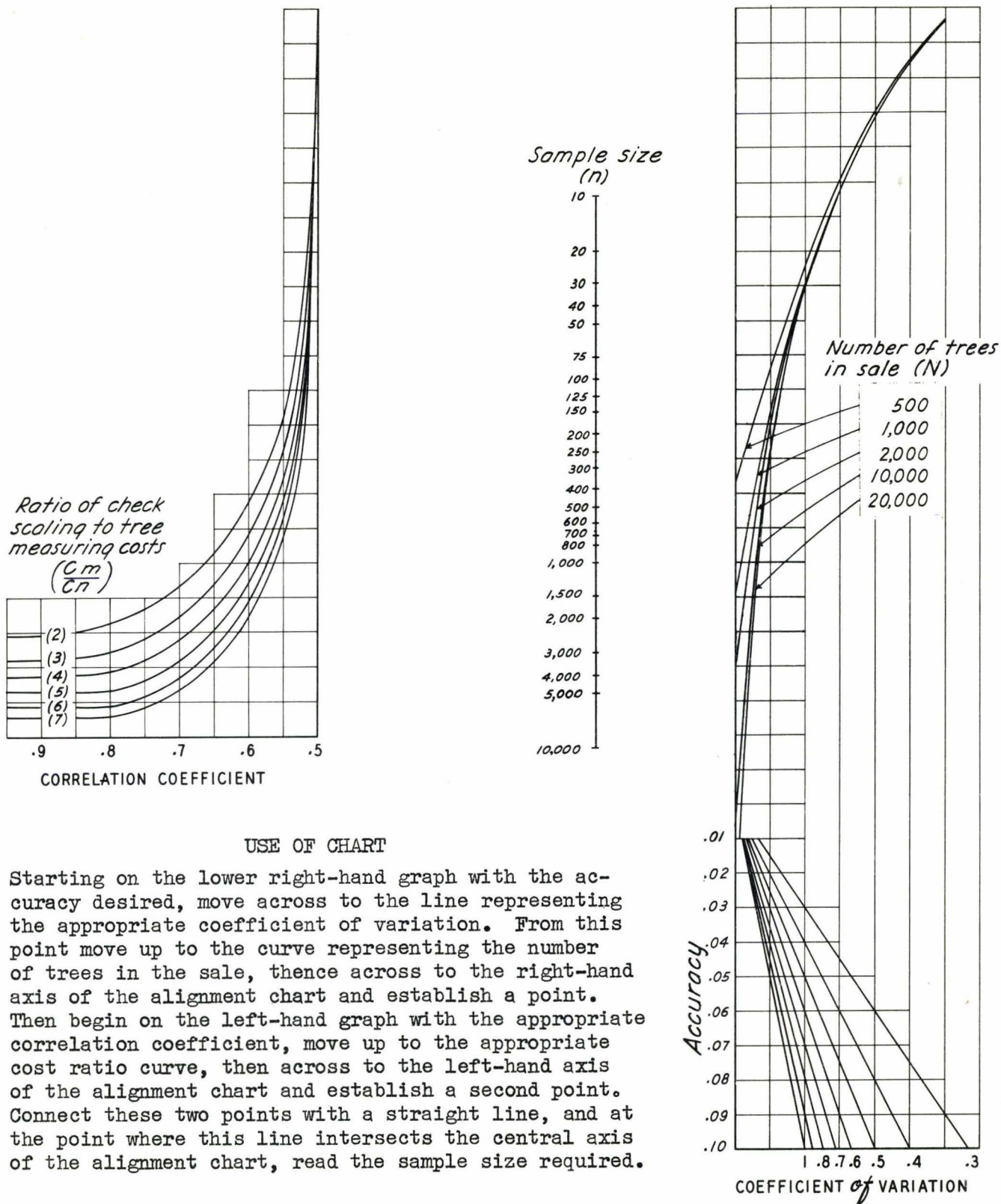


Figure 2.--Graph and alignment chart showing first sample size needed for various accuracies, coefficients of variation, sale sizes, correlation coefficients, and cost ratios.

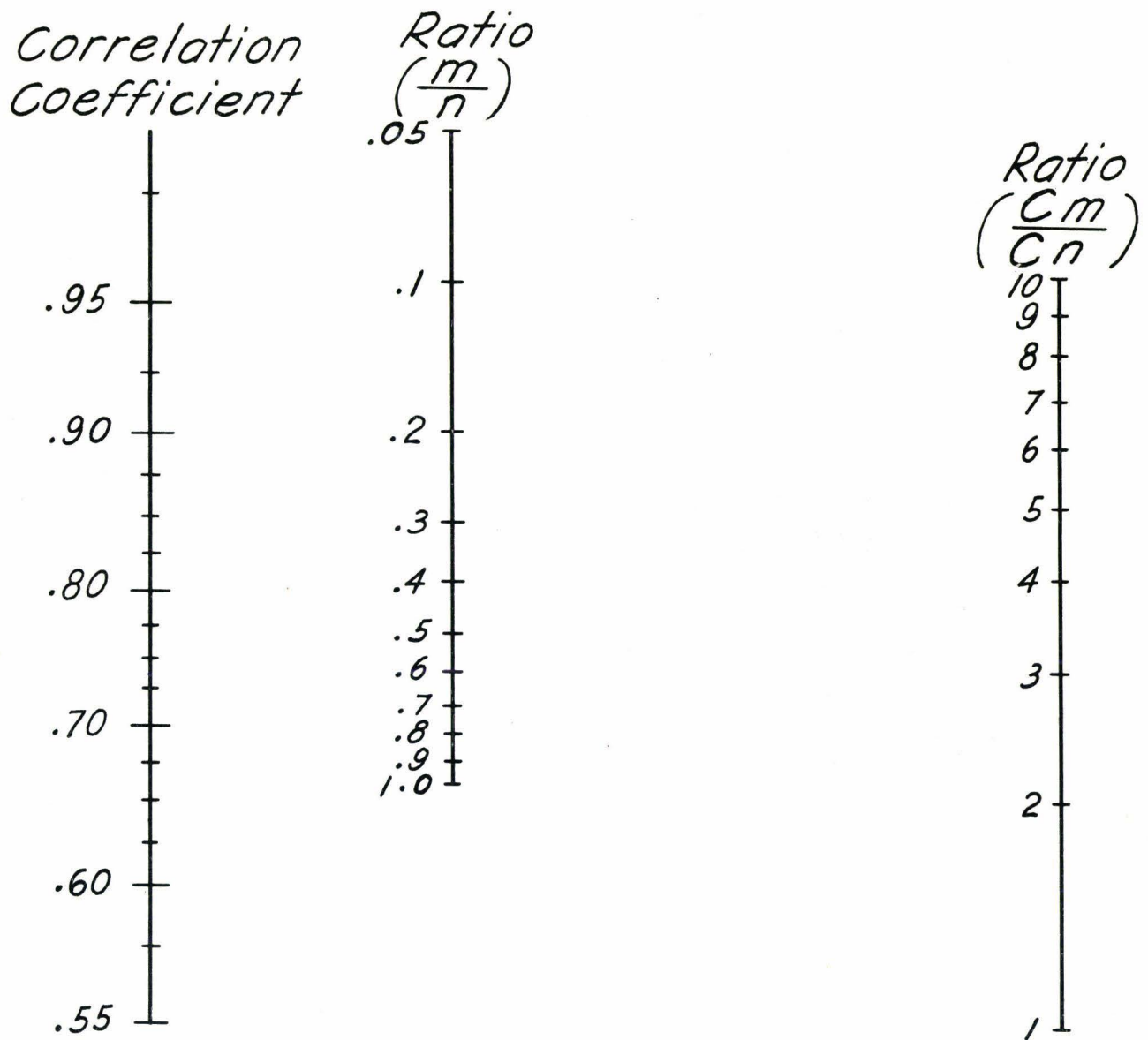


Figure 3.--Alignment chart showing the ratio of check scale sample size to first sample size ($\frac{m}{n}$), for various ratios of check scaling costs to tree measuring costs ($\frac{Cm}{Cn}$) and for various correlation coefficients.

Use of Figures 2 and 3 to determine sample sizes

The use of the chart in Figure 2 can be illustrated by the following example:

Given:	accuracy standard	0.03
	coefficient of variation	0.6
	sale size	2000
	correlation coefficient	0.8
	cost ratio	4.0

From the junction of the 0.03 accuracy line and the 0.6 coefficient of variation line in the lower right-hand graph, follow up to the intersection of the 2000-tree curve, and thence across (in a left-hand direction) to the right-hand axis of the alignment chart and establish a point. Now, starting on the left-hand graph, find the intersection of the 0.8 correlation coefficient line and the four cost ratio curve, and move across (in a right-hand direction) to the left axis of the alignment chart and establish a second point. Connect the two points with a straight edge, and read 500 trees for the sample size on the central axis of the alignment chart. The formula in Appendix VIII shows the exact answer to be 527 trees. The sampling rate would be one in four.

The amount of check scaling needed in the example which has been described can be determined from Figure 3. Connect with a straight edge the point for a correlation coefficient of 0.8 on the left-hand axis of the alignment chart with the point for a cost ratio of four on the right-hand axis, and read about a 0.4 ratio or factor on the central axis. This factor, 0.4, multiplied by 500 gives 200, the number of check scaled trees required. The operation can be checked by the formula in Appendix IX.

As the correlation is improved by better tree measuring, the number of trees needed in the first sample actually increases. But a look at the check scale size required when correlation is high clearly shows the advantage. As few as one-fifth of the measured trees need be check scaled when the correlation coefficient is 0.9 or better. Thus the big saving is made on the expensive part of the job, and increased emphasis is placed on the more easily obtained first sample.

APPLYING THE CHECK SCALE CORRECTION FACTOR

The usual and simplest method of computing the correction factor from the check scale data is to divide the checker's net volume by the estimator's net volume for the same trees. The total estimated volume obtained by the first sample or by a complete tally is then multiplied by the correction factor to give the final corrected net volume. The method is based upon the assumptions that (1) a line fitted to the plotted points of check scaled volume over estimated volume passes through the zero origin, (2) that the best fitting regression for the plotted points is a straight line, and (3) that the variation about the straight line is proportionate to the volume. In most cases, these assumptions are sufficiently correct for practical purposes. As has been pointed out previously, if the relationship does not meet these assumptions, a separate correction factor for size strata should be used.

In no case should the mean of the check scaled volumes be multiplied by the number of trees in the sale to determine the total volume. Multiplying the check scale mean volume by the total number of trees ignores the information of the first sample or complete tally and employs data from only a relatively few trees. It is not accurate. A check scale on a few representative trees can give a reliable correction factor without necessarily giving a reliable mean volume.

Contracts for timber sales on which tree volumes are to be determined by sampling must have strict rules concerning adjustments. A practice of adjusting the correction factor when a sale volume is questioned by the operator could result in a consistent loss to the seller, because underruns would bring complaints and overruns probably would not be mentioned.

THE POSSIBLE SAVING BY SAMPLING

Sampling can substantially reduce the cost of tree measurement. Although the costs have not been determined by accurate studies, they can be roughly estimated. Discussion with many forest officers and personal experience have led to the belief that marking and measuring 75 to 100 trees per man-day is an average accomplishment on tree measured sales. Under winter conditions daily production may be lower, but 100 trees per man-day is probably a safe average. The same sources of information give reason to believe that an average of 250 trees per man-day can be marked, without measuring. If \$20 per day is a fair estimate of the cost of one man-day, counting all expenses that are associated with the job, then 20 cents a tree is the cost of marking and measuring. As marking alone costs 8 cents per tree, the cost of measuring a sample tree is about 12 cents.

The possible saving by sampling can be estimated from the cost figures which have been cited. Assuming that the amount of check scaling would be the same in either sample tree measurement or total tree measurement, the measuring cost of 12 cents a tree can be used for purposes of comparison. From Figure 1, a comparison of number of trees in a sample with number of trees in the sale shows that total tree measurement might cost twice as much as sampling. About 10 cents per tree can be saved by sample tree measurement.

Sampling on timber sales is, naturally, more attractive to the seller than the buyer, for two reasons: first, the seller pays for the measuring job and is, therefore, interested in economy; second, for a seller, such as the Forest Service, who has many sales, the possible errors resulting from sampling tend to be compensating, although this is not strictly true when a wide range of stumpage values is involved. For a single purchaser, however, who does not have the advantage of many sales, the error, if any, could be to his disadvantage. For this reason, a purchaser might lower his stumpage bid if sampling methods are to be used on the sale, even though the possible error has a 50-50 chance of being in his favor.

SUMMARY

The increased use of tree measurement on Forest Service timber sales in the Northern Region and the desire to reduce the cost of routine measuring jobs in sales administration prompted this study of sample tree measurement. The study was expected to determine the applicability, work out methods, and establish sampling rates for the three species most commonly tree measured in the Northern Region -- ponderosa pine, Douglas-fir, and western larch.

In the study, samples were drawn from scale books on eight national forests. The samples included 24 sales in ponderosa pine stands, 22 in Douglas-fir, and 21 in western larch. In addition, 41 samples of check scale data were collected. As far as existing material permitted, a range in timber size, site, and defect conditions was covered.

The study showed that sampling in tree measured sales of the species mentioned is a practical method of volume determination, both in economy and accuracy. Although cost figures are inadequate, it is estimated that a saving of about 10 cents a tree can be made by sampling. The sample size and consequent sampling rate for a sale of a particular number of trees are dependent upon several factors.

1. Accuracy desired

When accuracy demands are lowered, a marked reduction in sample size results. From the seller's point of view, accuracy need not be high because (a) low accuracy means a saving in the volume determination job and (b) errors tend to compensate over many sales. From the purchaser's point of view, high accuracies are desirable because he may not have the number of sales necessary to cause the possible errors to compensate. The accuracy standard should not be the same for every sale. The cost of measuring as well as the total value of the sale should be considered, because a rate can be reached in sampling where additional expense of measurements is not justified by the possible gain in accuracy.

2. Amount of variation in tree volumes

Although the relative variation (coefficient of variation) is reasonably uniform for all species and size classes, sufficient range in variation exists to influence the sample size materially. An estimate of the variation for a particular sale is needed before determining the sample size and subsequent sampling rate. Variation can be estimated from cruise data, from a small preliminary sample, or from a good knowledge of the timber concerned. (See table in Appendix 1.)

3. Use of stratified sampling

Stratified sampling, that is, sampling large and small trees, or large, medium and small trees independently, materially reduces the sample size needed for a given accuracy. If the dividing point between the large and small strata is chosen properly, all of the large trees can be measured and the sample drawn from the remainder with a net saving in number of trees measured. Further reduction in sample size can be made by increasing the number of strata.

Figure 1 gives sample sizes required on sales for a range of numbers of trees, variations, and accuracies. Sample sizes read from this chart will give estimates of complete tree measured volume within the accuracies shown and for a probability of 68 percent. Estimating log-scaled volume requires a correction based on a check scale.

Check scaling involves scaling the logs of certain full length trees after felling and bucking and dividing the scaled volume by the estimated volume of the same trees to determine a correction factor. The number of trees to be check scaled in order to arrive at a reliable correction factor depends upon the precision of volume determinations for individual trees. The closer the estimated volume of each tree agrees or is correlated with its scaled volume, the fewer check scaled trees are needed. Improved height and defect estimates and a high degree of accuracy in the application of volume tables are necessary in order to obtain good correlation between the measured and check scale volume.

When check scaling is planned, that is, when the sampling process is designed to estimate log-scaled volume, the sample size should be determined from Figure 2 in which the correlation coefficient of tree measured and check scaled volumes and the cost ratio of the two processes are considered along with the other variables. The number of trees needed in the check scale under various conditions can then be determined from Figure 3.

Check scaling presents a problem because of the difficulty of finding full-length trees felled and bucked in the woods under present logging methods. With the use of sampling this difficulty is magnified, because only sample trees can be check scaled. Conspicuously marking sample trees aids in locating them for scaling purposes. With improved skill in tree measurement, check scaling can be materially reduced.

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APPENDIX

I. SAMPLE TREE MEASUREMENT TRAINING OUTLINE 1/

Crew organization

A three-man crew is the ideal size for sample tree measurement. One man is designated the tallyman whose job is to record the data from the sample trees and keep the count on all trees. He can often aid in tree selection and in height estimation as well. The other two men are markers who select, mark, and measure trees. If only two men are available, they can operate fairly efficiently if the tallyman aids in selecting trees and estimating heights. One man alone cannot properly do the sample tree measurement job if two or more species are being sampled because of the difficulty of randomly selecting sample trees.

Assumptions regarding previous knowledge and skills of trainees

It is assumed that trainees in sample tree measurement will be qualified timber markers. They will, therefore, be experienced in measuring d.b.h. and heights, and in estimating defect in the standing trees. Instructions in these phases of the job will not be included in this training procedure.

Material and equipment requirements

The following items of equipment and materials will be required for the sample tree measurement training program.

1. Letter-size tatum holder with pages index-tabbed for rapid location of proper tally sheet.
2. Tally sheet forms (samples of which are included in this training outline).
3. Paint guns or marking axes for tree marking. (Paint guns are recommended.)
4. Aluminum numbering tags or bottle top tags. (If trees are blazed, they can be numbered with lumber crayon.)

1/ This training outline was prepared with assistance from Victor O. Sandberg, Division of Personnel Management, Northern Region, U. S. Forest Service.

5. Diameter tape. (Drag tape recommended.)
6. Scale rule. (Calipers are occasionally valuable when log ends are not exposed.)
7. Abney level for checking tree heights.
8. Volume tables (preferably tables made up for inch diameter classes and one-half log heights.)
9. Copies of this publication for reference.
10. A few pages of random numbers for office and field use.

Selection of training area

The area chosen for training in sample tree measurement should be a timber sale on which cut trees are to be marked and preferably where log scaling is contemplated. The trees marked in conjunction with the training can therefore apply to the timber sale and the measurement can be incidental. A sale involving two or more species should be chosen in order to give a good representation of the job on typical timber sales. For the check scale phase of the job, a sale on which cutting is in progress should be chosen. Felled, bucked trees are needed for training in check scaling. In this phase of the training emphasis should be placed on getting a representative check scale, that is, a sample of measured trees well distributed over the sale area as well as over the range of tree sizes.

Job breakdown

The following steps and key points for sample tree measurement are based on training by the job-breakdown method which is being used in many other phases of Forest Service work. Other jobs closely associated with sample tree measurement, such as timber marking and log scaling have also been described by this method of training.

Preliminary office work

Important steps in the operation	Key points
1. Estimate number of trees by species in the sale a. From cruise data b. Alternate system--Divide total volume each species by estimated average volume of single tree	Basic data taken from cruise sheets. Keep species separate. Eliminate all "large" trees, usually about the upper 10 to 20 percent. See page 11 of this publication. Used if no cruise data available. Average volume of single tree determined from past experience or from previous sale reports on similar areas.
2. Estimate coefficient of variation for each species	See Appendix III of this publication for formulae. For a rough guide to the coefficient of variation for different species and conditions, refer to the following table:

Coefficient of Variation Guide 1/

Description of stand	Species		
	Ponderosa pine Engelmann spruce Grand fir	Western white pine	Douglas fir Western larch Lodgepole pine
Uneven aged, large variation in tree sizes, considerable defect	0.7-0.8	0.6-0.8	0.6-0.8
Even aged, trees fairly uniform in size, little defect	0.5-0.7	0.5-0.6	0.4-0.6

1/ Select a coefficient from within the range shown for a particular situation. For more variable timber select values near the top of the range; for less variable timber select values near the lower part of the range. If more precise estimates of the coefficient are desired, use the formula in Appendix III.

When all large trees are tallied separately, deduct one-tenth unit from the chosen coefficient of variation.

Preliminary office work (cont.)

Important steps in the operation	Key points
3. Select accuracy standard	Established by supervisor's office or regional office.
4. Estimate correlation coefficient of check scaled and tree measured volumes	Based on previous knowledge from other sales of similar timber, same volume table and same personnel. See Appendix V. For a rough guide to the correlation coefficient refer to the following table:

Correlation Coefficient Guide 1/

Description of situation	Correlation Coefficient (r)
Check scale of individual trees agrees closely with tree measurements or is consistently high or low by a constant percentage	0.9
Check scale of individual trees generally agrees closely, but occasional trees differ widely and inconsistently	0.8
Check scale and tree measurements differ without predictable pattern, with one volume being too high, the next much too low, etc.	0.6

1/ Select values intermediate to those given in the table for situations which appear to be intermediate. For more precise estimates, use formula given in Appendix V.

5. Estimate ratio of cost of check scaling to cost of tree measuring a tree	Based on experience or best estimate. See page 21 of this publication.
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Preliminary office work (cont.)

Important steps in the operation	Key points
6. Using accuracy, coefficient of variation, number of trees in sale, correlation coefficient, and cost ratio, determine sample size for each species and stratum	Refer to Figure 2, page 22 of this publication, or to formulae in Appendix VIII. If no check scaling is contemplated, that is, if the sample is for the purpose of estimating tree measured volume instead of scaled volume, the sample size is determined from Figure 1, page 7. Correlation coefficient and cost ratio need not be determined for use of this graph.
7. Calculate sampling ratio for each species and stratum	Divide total number of trees in a species or stratum group by sample size. Round off to nearest whole number.
8. Prepare field sampling forms a. Determine number of "tree count numbers" needed in each section of form b. Choose one number at random from each sampling rate interval c. Encircle numbers chosen for sample trees	See sample form, "Sample Tree Measurement Tally Sheet" on the following page. Prepare separate forms for each species and stratum to be sampled. Be sure an adequate supply is prepared. Found by multiplying sampling ratio by 4 (because four spaces are provided in each section of the sample form). Cross out any additional numbers not needed. For example, a 1 in 5 rate would use only 20 numbers, while a 1 in 10 rate would use all 40 numbers. Rates less than 1 in 10 can be used, but all the spaces for recording tree measurements in each section of the form will not be filled. For example, a 1 in 20 ratio would fill only two spaces in each section, but would use all 40 numbers. If the sample form shown here does not apply well to the conditions encountered, forms can be made up with appropriate spaces and "tree count numbers" in each section. Use random numbers as described in Appendix X.

Field procedure

Important steps in the operation	Key points
1. Marker: Select a tree to be cut. Mark it.	Mark trees at breast height and on the stump either with a blaze or with a paint gun.
2. Marker: Notify tallyman that a tree has been selected.	By telling <u>species</u> and approximate size. Example: "A 20-inch larch." Size determined by ocular estimate. Calling the <u>estimated</u> size enables the tallyman to place the tree in the proper stratum. Special care should be taken in estimating border-line trees so that the tree count by strata will not be biased. Measuring border-line trees will prevent any bias.
3. Tallyman: Count tree and acknowledge to marker that tree is recorded.	By putting a slant mark through number one of the "tree count numbers" on the appropriate tally sheet. Acknowledge by repeating the tree size and species.
4. Tallyman: Determine if tree is a sample tree or not.	Sample tree numbers have been previously chosen and encircled. Tree is counted whether it is a sample tree or not.
5. If tree is a sample tree, tallyman tells marker to measure it.	Acknowledge as before and in addition say "measure it."
6. Marker: Measure d.b.h. and estimate height and defect. Number tree.	D.b.h. measured to nearest inch with a diameter tape. Height estimated to nearest one-half log (8 feet), to merchantable top, determined from volume table. Defect estimated as a percentage of volume. Mark sample trees conspicuously.

Field procedure (cont.)

Important steps in the operation	Key points
7. Marker: Call out measurements and tree number to tallyman.	If tags are being used, marker will tell tallyman the tree number. If crayon is used, tallyman will call out a number to the marker. In this case a separate series of numbers should be used for each species and size stratum so the tallyman will not have to thumb through other pages to see what the next number should be. The use of tags eliminates this difficulty.
8. Tallyman: Record data of sample tree.	Record tree number, d.b.h., height, and cull percentage in space provided.
9. Marker: Number sample tree.	Use aluminum numbering tags, or if trees are being blazed, numbers can be written on blaze with a crayon.
10. Marker: Measure and number all "large" trees, as they are encountered.	Same measurements as made on sample trees.
11. Tallyman: Record measurements of all "large" trees on special form provided.	Form for large trees is different from sampling form. See sample on following page.
12. Marker: Measure and number all trees of species which are not plentiful enough to sample.	Species in this category determined in advance of field work.
13. Tallyman: Record measurements of all trees measured in 12 above on separate form.	This form the same type as one used for large trees.

Page

(Sale Designation)

(Date)

[illegible]

No. measured: Total volume:

Office work to be done following field work

Important steps in the operation	Key points
1. Record net volume of each sample tree in space provided on sampling form.	Volumes read from appropriate volume tables. Adjust volumes for any cull that was recorded at time of measurement.
2. Add up volume of sample trees.	
3. Multiply total volume (obtained in 2 above) by sampling ratio. Enter this final volume in space provided.	If the sampling form was not completely filled, the multiplying factor is determined by dividing the number of trees marked by the number of sample trees measured on that particular form. Or, if desired, multiply the mean volume of the sample trees on the form by the total tree count on the form to get estimated total volume.
4. Record net volume of each large tree measured.	Volumes read from same volume table as used in 1 above.
5. Add up volumes of large trees.	

Check scale--office work

Important steps in the operation	Key points
1. Determine correlation coefficient of estimated volume and check scale volume.	For each species and stratum, based on previous experience for similar conditions. Can be computed after check scaling a few trees for a basis. See Appendix V of this publication. This will be a refined estimate of the correlation coefficient used in step 4 under "Preliminary office work."

Check scale--office work (cont.)

Important steps in the operation	Key points
2. Estimate ratio of cost of check scaling to cost of tree measuring a tree.	Based on experience or best estimate. See page 21 of this publication. Same ratio used in step 5 under "Preliminary office work."
3. Determine number of trees needed in check scale sample. a. Determine ratio of number of check scale trees to number of trees in first sample, $(\frac{m}{n})$. b. Multiply number of trees in first sample by ratio (a) above to get number of trees needed in check scale sample.	Using correlation coefficient (No. 1 above), and cost ratio (No. 2 above). Refer to Figure 3, page 23 of this publication, or formula in Appendix IX.

Check scale--field work

Important steps in the operation	Key points
1. Locate felled and bucked sample tree.	By conspicuous markings. Identification by tags or keel number.
2. Scale logs in tree.	Carefully and accurately. See job breakdown for scaling. If log ends are not exposed, use calipers or a diameter tape whichever is more practicable, then deduct for double bark thickness. Deduct for defect and breakage.
3. Record tree number, species, log length and gross and net volume by logs.	
4. Add up net volume of individual logs to give net tree volume.	

Final office work

Important steps in the operation	Key points
1. Add up volume of check-scaled trees by species.	
2. Add up tree measured volume of the same trees.	Volume taken from appropriate field sheets.
3. Divide item 1 by item 2 above. This quotient is the correction factor.	Refer to page 25 of this publication. Each species will have a separate correction factor. It might also be found that each size stratum should have a separate correction factor. This can be determined by plotting check-scaled volumes for all strata over estimated volumes of the same trees. If the trend appears to be a straight line, which passes through the zero origin, then a common correction factor for all size strata can be used. If it is noticeably above or below the zero origin or noticeably curved, then separate factors should be calculated and used.
4. Multiply total tree measured volume by the appropriate correction factor to obtain final estimated net volume.	Use a form similar to the one on the following page.
5. Add net volume of each size stratum (if they were corrected separately) to obtain total estimated net volume for each species.	

SAMPLE TREE MEASUREMENT SUMMARY SHEET

		<u>Date</u>	
<u>Forest</u>	<u>District</u>	<u>Sale Designation</u>	
<u>Species</u>			
<u>From the sample</u>	<u>Uncorrected volume</u>	<u>Correction factor</u>	<u>Net volume</u>
Stratum 1, pages ___ to ___	___	___	___
Stratum 2, pages ___ to ___	___	___	___
Stratum 3, pages ___ to ___	___	___	___
<u>From complete tally</u>			
pages ___ to ___	___	___	___
Total			___

II. FORMULA FOR COMPUTING THE STANDARD DEVIATION 2/

$$S = \sqrt{\frac{\sum (y^2) - \frac{(\sum y)^2}{n}}{n - 1}}$$

where s = standard deviation of the sample of tree volumes

y = volume of a single tree

Σ = "the sum of"

n = number of individual tree volumes in the sample

III. FORMULA FOR COMPUTING COEFFICIENT OF VARIATION

$$CV = \frac{s}{\bar{y}}$$

where CV = coefficient of variation

s = standard deviation

$\bar{y}$ = mean volume of sample

IV. FORMULA FOR COMPUTING SAMPLE SIZE

$$n = \frac{t^2 (CV)^2}{E^2 + \frac{(CV)^2}{N} t^2}$$

where n = number of trees needed in the sample

t = number of standard units chosen in the probability limits

CV = coefficient of variation

E = accuracy desired, expressed as a certain percentage of the mean

N = number of trees in the sale

If a probability of 68 percent is considered sufficient (as has been used throughout this report) then t = 1 and the formula becomes:

$$n = \frac{(CV)^2}{E^2 + \frac{(CV)^2}{N}}$$

(This formula is the basis for data in Figure 1.)

2/ For more details in the method of calculating this and other statistics, see Schumaker and Chapman (11) or other texts on statistical methods.

V. FORMULA FOR COMPUTING THE CORRELATION COEFFICIENT
BETWEEN TREE MEASURED AND CHECK SCALED VOLUMES

$$r = \frac{\sum(MC) - \frac{(\sum M)(\sum C)}{n}}{n - 1} \frac{1}{s_m s_c}$$

where r = correlation coefficient

M = an individual tree volume determined by the marker

C = the corresponding volume determined by the check scaler

Σ = "the sum of"

n = number of pairs of volumes in the sample

s_m = standard deviation of tree measured volumes

s_c = standard deviation of scaled volumes

VI. STRATIFIED SAMPLING

When "large" trees are all tallied and the remainder sampled, the allowable error of the remainder can be larger than has been established for the final result. The following formula adjusts the over-all accuracy (E) for use in this type of sampling.

$$E_2 = E \left(\frac{N}{N_2} \right) \left(\frac{\bar{\bar{y}}}{\bar{y}_2} \right)$$

where E_2 = allowable error (accuracy) of "remainder" group

N = total number of trees in sale

N_2 = number of trees in the "remainder" group

$\bar{\bar{y}}$ = mean volume of all trees (determined from cruise data)

$\bar{y}_2$ = mean volume of all trees in "remainder" group

The following steps outline the method of selecting the best dividing point of large trees:

1. From cruise data or from a preliminary sample, compile a frequency distribution of tree volumes.
2. Compute the mean, standard deviation, and coefficient of variation from the frequency table. (See Appendices II and III.) The sample size needed (n) if no stratifying is to be done can be determined from these data using the formula in Appendix IV, or Figure 1.
3. Select an arbitrary dividing point for large trees and "remainder." The number of large trees (N_1) plus the number of remainder (N_2) equals total sale size (N).
4. Compute a new mean, standard deviation, and coefficient of variation for the "remainder" group. (Since the large group will be tallied completely, it will not contribute to the sampling error.)
5. Compute the adjusted accuracy (E_2) for this remainder group using formula in Appendix VI.
6. Using E_2 , CV_2 , and N_2 compute a new sample size (n_2).
7. Add n_2 and N_1 to give the total number of trees to be measured. This total will be smaller than n unless the dividing point was too low and placed too many trees into the large group. However, it probably will not be the smallest possible number unless a lucky choice was made in selecting the dividing point.
8. Repeat the process with different dividing points until the smallest total ($n_2 + N_1$) is obtained.

VII. FURTHER STRATIFICATION

If it is desired to stratify further by dividing the "remainder" group into two strata, the following formulae will give the sample sizes needed. Symbols:

Tree size	Number trees in sale	Mean volume	Standard deviation	Number trees in sample
Small	N_s	$\overline{y}_s$	s_s	n_s
Medium	N_m	$\overline{y}_m$	s_m	n_m
Small plus medium	N_2	$\overline{y}_2$	s_2	n_2
Large	N_1	$\overline{y}_1$	—	—
Total	N	$\overline{y}$	s	n

$$n_2 = \frac{(N_s S_s + N_m S_m)^2}{N_2^2} \frac{1}{S_{\bar{y}_2}^2 + \frac{N_s S_s^2 + N_m S_m^2}{N_2^2}}$$

where $S_{\bar{y}_2}$ is estimated from $S_{\bar{y}} \left(\frac{N}{N_2} \right)$

$$S_{\bar{y}} = E(\bar{y})$$

E = accuracy standard

$$\text{then } n_s = \frac{N_s S_s}{N_s S_s + N_m S_m} (n_2)$$

$$\text{and } n_m = n_2 - n_s$$

VIII. SAMPLE SIZE NEEDED FOR ESTIMATING SCALED VOLUME (BASIS FOR FIGURE 2)

$$n = \frac{\sqrt{2 - 2r} \sqrt{-1 + 2r} \sqrt{\frac{C_m}{C_n}} + (-1 + 2r)}{\left(\frac{E}{CV} \right)^2 + \frac{1}{N}}$$

where n = sample size

r = correlation coefficient of tree measured
volumes and check scaled volumes

Cm = cost of check scaling a sample tree

Cn = cost of tree measuring a sample tree

E = accuracy

CV = coefficient of variation

N = number of trees in sale

IX. NUMBER OF TREES REQUIRED IN THE CHECK SCALE (BASIS FOR FIGURE 3)

$$\frac{m}{n} = \frac{\sqrt{2 - 2r}}{\sqrt{-1 + 2r}} \sqrt{\frac{C_n}{C_m}}$$

where $\frac{m}{n}$ = ratio of number of trees in check scale
to number of trees in first sample

X. USE OF RANDOM NUMBERS

The use of random numbers is the quickest and best method of selecting sample trees at random. Pages of random numbers can be found in "Converting Factors and Tables of Equivalents Used in Forestry", U. S. Dept. Agr. Misc. Pub. 225, and in many statistical books.

A random starting point is selected on a page of the random numbers, and either one or two columns of digits are used depending upon the sampling rate. If the rate is one in three, four, or up to ten, then only one column is required. The digits are merely noted in consecutive order, and those that are inappropriate discarded. For example, if a rate of one in five is in use, the digits 0, 6, 7, 8, and 9 would be disregarded. As numbers from one to five are encountered, the appropriate numbers on the sample tree measurement tally sheet would be encircled. The first number might be 4, so number 4 in the first group of five numbers would be encircled. The next number might be 1, so number 6 (the "1" in the next series of five) would be encircled. In this example, only 20 of the sample tree designation numbers in each section of the tally sheet would be used and the remaining 20 crossed out.

If the sampling rate is one in ten, one column of digits can be used if zero is considered 10. For sampling rates less than one in ten, two columns of digits will be needed. For example, with a rate of one in 20, all numbers from 01 to 20 would be used while numbers 00, and 21 to 99 would be disregarded.

LIST OF PREVIOUS PUBLICATIONS IN THIS SERIES

Station
Paper
No.

- 1 ° A preliminary study of root diseases in western white pine,
by John Ehrlich. Oct. 1939.
 - 2 ° Possibilities of partial cutting in young western white pine,
by E. F. Rapraeger. Jan. 1940.
 - 3 Blister rust control in the management of western white pine,
by Kenneth P. Davis and Virgil D. Moss. June 1940.
 - 4 Possibilities of wood-pulp production in the northern Rocky
Mountain region, by E. F. Rapraeger. Mar. 1941.
 - 5 Results to date of studies of the durability of native woods
treated and untreated, by C. N. Whitney. Rev. Jan. 1946.
 - 6 Changes in Benewah County forest statistics, by Paul D. Kemp.
July 1947.
 - 7 ° A guide for range reseeding on and near the national forests
of Montana, by C. Allan Friedrich. Oct. 1947.
 - 8 Pole blight - a new disease of western white pine, by C. A.
Wellner. Nov. 1947.
 - 9 Management practices for Christmas tree production, by C. A.
Wellner and A. L. Roe. Nov. 1947.
 - 10 The merits of lodgepole pine poles, by I. V. Anderson.
Nov. 1947.
 - 11 Tables for approximating volume growth of individual trees,
by P. D. Kemp and M. E. Metcalf. March. 1948.
 - 12 Forest resource statistics, Cascade County, Montana, by H. J.
Pissot and E. F. Pepper. Apr. 1948.
 - 13 Forest resources of northern Montana, by C. W. Brown and W. C.
Hodge. June 1948.
 - 14 List of publications available for distribution or loan,
1910 through 1947. NRM station. June 1948.
 - 15 Review of published information on the larch-Douglasfir
forest type, by Russell K. LeBarron. Nov. 1948.
- ° Out of print. Loan copies may be obtained upon request.

Station
Paper
No.

- 16 Development of a blister rust control policy for the national forests in the Inland Empire, by Donald N. Matthews and S. Blair Hutchison. Dec. 1948.
- 17 Disintegration of girdled western hemlock and grand fir, by Austin E. Helmers. Dec. 1948.
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- 22 Bibliography of ponderosa pine, by A. L. Roe and K. N. Boe. March 1950.
- 23 Forest resources of south central Montana, by T. L. Finch, W. C. Hodge, and M. E. Metcalf. Apr. 1950.
- 24 The cubic foot as a national log-scaling standard, by E. F. Rapraeger. June 1950.
- 25 Montana forest resource and industry statistics, by Paul D. Kemp and M. B. Dickerman. Oct. 1950.
- 26 St. Johnswort on western ranges, by Grant A. Harris. Feb. 1951.